Sea Surface Temperature from the VIIRS Instrument During NPOESS

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Introduction

Abstract:
The National Polar-orbiting Operational Environmental Satellite System [NPOESS] is being developed to replace the current NOAA Polar Orbiting Environmental Satellite (POES) and the DoD Defense Meteorological Satellite Program (DMSP) systems. The instruments generally will represent significant improvements over the current operational sensors. For example the Visible-IR Imager Radiometer Suite [VIIRS] with 22 channels will be replacing the 6-channel Advanced Very High Resolution [AVHRR] on the POES system and the 3-channel Operational Line Scanner [OLS] on the DMSP system. Measurements of the sea surface temperature from NPOESS, will come from the VIIRS instrument. The sea surface temperature Environmental Data Record (EDR) will be derived from the moderate resolution thermal emissive channels covering the short-wave and long-wave infrared spectral regions (3.7 to 12.05 μm). Both skin and bulk sea surface temperature will be retrieved. The VIIRS sea surface temperature retrieval algorithm will be described and performance results using both simulated and MODIS proxy data will be presented.

SST Requirements:
Both skin and bulk SST are produced for all cloud free pixels; however, different requirements are specified for skin and bulk SST and for favorable and unfavorable conditions. Under favorable conditions, defined as being within 40 degrees of nadir, sea surface temperature less than 285 K, negligible cloud cover, and aerosol optical thickness less than 0.2, skin SST is required to have an uncertainty of 0.35 K and precision of 0.27 K, and bulk SST is required to have an uncertainty of 0.5 K and precision of 0.27 K. Under unfavorable conditions, defined as negligible cloud cover and one or more of the following conditions: sensor zenith angles between 40 and 50.3 degrees off nadir, sea surface temperature greater than 285 K but less than 313 K, aerosol optical thickness greater than 0.2 but less than 1.0, the requirements on skin SST are 0.50 K for uncertainty and 0.45 K for precision, and the requirements on bulk SST are 0.50 K for uncertainty and 0.45 K for precision. These precision and uncertainty requirements must be met across the entire performance measurement range of 271 K to 308 K. This is particularly challenging requirement since all regression based SST algorithms perform much worse at temperatures above ~305 K. This deficiency is reflected in the test results presented below.

VIIRS SST Algorithm Description

The VIIRS Sea Surface Temperature algorithm consist of two products, bulk and skin SST. Each product uses three separate algorithms. The algorithms used are the same for both product but will have separate sets of regression coefficients. The three algorithms are: the split window algorithm, used in daytime sun glint, the daytime dual split window algorithm, used in daytime outside the sun glint region, and the nighttime dual split window algorithm, used at night. Each algorithm has twelve sets of regression coefficient. The regression coefficient stratifications are defined as follows: four temperature / moisture regimes (cold, warm dry, warm average, warm moist) times three aerosol levels (low, medium, high).

Split Window Algorithm

$$SST = a_0 + a_1 T_{11} + a_2 (T_{11} - T_{12}) + a_3 (\sec(z) - 1) + a_4 (T_{11} - T_{12})^2$$

Daytime Dual Split Window Algorithm

$$SST = a_0 + a_1 T_{11} + a_2 T_{12} + a_3 (\sec(z) - 1) + a_4 T_{3.7} + a_5 T_{4.0} + a_6 T_{3.7} \cos(zs) + a_7 T_{4.0} \cos(zs) + a_8 (T_{11} - T_{12})^2$$

Nighttime Dual Split Window Algorithm

$$SST = a_0 + a_1 T_{11} + a_2 T_{12} + a_3 (\sec(z) - 1) + a_4 T_{3.7} + a_5 T_{4.0} + a_6 T_{3.7}{}^2 + a_7 T_{4.0}{}^2 + a_8 (T_{11} - T_{12})^2$$

$T_{3.7}$ = *Brightness Temperature (K) for band M12 (3.700 μm)*

$T_{4.0}$ = *Brightness Temperature (K) for band M13 (4.050 μm)*

T_{11} = *Brightness Temperature (K) for band M15 (10.763 μm)*

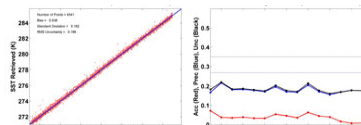T_{12} = *Brightness Temperature (K) for band M16 (12.013 μm)*

zs = *Solar Zenith Angle*

z = *Sensor Zenith Angle*

Results of Testing with Global Synthetic Data

Synthetic Data Set Description:
To build the global test datasets, NGST has compiled environmental information from NCEP. The NCEP AVN-FNL tropospheric datasets provide a fairly complete set of geophysical parameter values describing the state of the atmosphere and terrain/ocean background. This data have been assimilated from a number of sources (radiosondes, buoys, and satellite) and re-generated onto a uniform 1 degree equal-angle lat/lon grid covering the globe. Atmospheric profiles of temperature, geo-potential height, relative humidity, cloud liquid water, ozone, and vector-winds are specified at up to 25 pressure levels, from 1000 mb to 10 mb. In addition to atmospheric profiles, the NCEP tropospheric datasets provide a rather extensive set of near-surface, surface and subsurface geophysical properties including surface elevation, air-temperature (2m height), pressure, vector-winds (10 m height), relative humidity (2m height), skin temperature, soil subsurface-profiles of moisture content and temperature (0-10 cm and 10-200 cm), snow cover, and land/sea and ice masks. This data is available four-times daily, at 00Z, 06Z, 12Z, and 18Z. The global environmental data for the current EDR assessments is based on 12 days of NCEP analyses, consisting of 1 days/month between July 2001 and June 2002. This data set provides an ensemble of over 3 million surface/atmosphere situations that can be sampled to construct the global test datasets and provide truth values of all relevant geophysical parameters required to evaluate EDR performance for a number of NPOESS products.

Using the global environmental data from the 12 days of NCEP analyses, we simulated the NPOESS 1330, 1730, and 2130 orbits and sampled subsets of this data, using the VIIRS swath and scan specifications, to generate the global test datasets for assessing EDR performance. In all, we extracted about 350,000 surface/atmosphere situations as test samples for the EDR performance. The geophysical parameters and viewing conditions were input into the MODTRAN-4, Version-1 Release-2 radiative transfer model to compute top of the atmosphere radiances. These TOA radiances were fed into a detailed sensor model of the VIIRS instrument to obtain calibrated Sensor Data Records (SDRs) with realistic post-calibration sensor effects.

Synthetic Data Set Results:
The results presented in the figures below are based on the VIIRS 1330 orbit with sensor effects based on nominal operating conditions. Cloud clearing was done using the true knowledge of cloud location; therefore, these results represent best case performance (i.e. no residual cloud contamination). As can be seen, the precision and uncertainty computed for Skin SST using the global synthetic data set meet NPOESS system requirements across the entire range of conditions available. In addition, the predicted global RMS uncertainty is superior to the performance achieved by the AVHRR and MODIS heritage sensors.
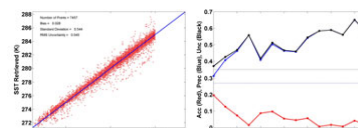

VIIRS Skin SST Performance under Favorable Conditions
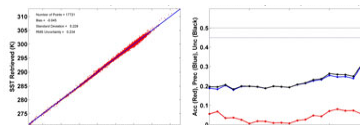
VIIRS Skin SST Performance under Unfavorable Conditions

Results of Testing with MODIS Match-up Data

**MODIS Terra Match-up Data Set Description:**
Data set provided to the NPOESS program by the University of Miami, Rosenstiel School of Marine and Atmospheric Science. Consists of four years of MODIS Terra data, 2001 through 2004. Total of 57593 data points for Bulk SST (buoys). Data is both day and night and covers a broad range of temperatures. Total of 2519 data points for Skin SST (MAERI radiometers). Data is both day and night and consists of predominantly warmer temperatures.

**MODIS Terra Match-up Data Set Results:**
The data set was screened for residual cloud contamination and erroneous buoy measurements prior to computation of performance metrics; however, the asymmetry in the distribution of outliers suggests that the cloud clearing tests were not 100% effective. The precision and uncertainty computed for Skin SST, unfavorable conditions using the MODIS Terra match-up data set comes very close to meeting NPOESS system requirements across the entire range of conditions. No performance statistic were computed for Skin SST, favorable conditions due to the lack of radiometer data in the lower range of sea surface temperatures. The precision and uncertainty computed for Bulk SST, favorable conditions using the MODIS Terra match-up data set do not meet NPOESS system requirements across the entire range of conditions. It is unlikely that any regression based algorithm will be able to achieve these ambitious performance requirements. The precision and uncertainty computed for Bulk SST, unfavorable conditions using the MODIS Terra match-up data set meets NPOESS system requirements across a considerable portion of the measurement range. If, as expected, VIIRS has better noise characteristics than MODIS Terra in the thermal IR, it will be possible to meet NPOESS system requirements for temperatures less than 303 K. Despite the problem with meeting the aggressive system specification for Bulk SST, the predicted global RMS uncertainty for VIIRS is comparable to, or better than performance achieved by the AVHRR and MODIS heritage sensors.

VIIRS Bulk SST Performance under Favorable Conditions
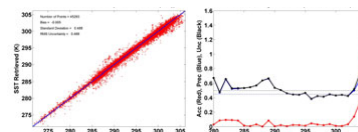
VIIRS Bulk SST Performance under Unfavorable Conditions
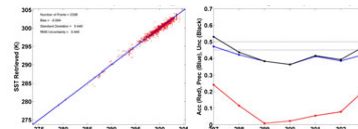
VIIRS Skin SST Performance under Unfavorable Conditions

Summary

The VIIRS SST algorithm has been rigorously tested with both synthetic and proxy data. The results are encouraging, though not entirely satisfactory. The VIIRS SST algorithm is expected to meet NPOESS system requirements for Skin SST for sea surface temperatures less than 305 K. The current regression based algorithm will have difficulty meeting NPOESS system requirements for Bulk SST, particularly at higher temperatures. However, the performance is expected to be comparable to, or better than, performance of the AVHRR and MODIS heritage sensors. A potential improvement in the performance of the Bulk SST may be achieved by developing a physical retrieval from the skin SST that would utilize cross-sensor data from the CrIMSS and MIS instruments onboard the NPOESS spacecraft.